09-22-00

A

Assistant Commissioner for Patents
Washington, DC 20231
ATTN: BOX UTILITY APPLICATION

Sheet 1 of 2

UTILITY
PATENT APPLICATION
TRANSMITTAL
Docket No.: 99-463
Date: September 21, 2000

U.S. Express Mail Label No.: EI883567969US

Inventor Name(s):
XIAO CHEN; YI DONG; AND ASHOK NANJUNDAN

Title:
METHOD AND APPARATUS FOR PROVIDING A SIMULATION OF A WELDING PROCESS USING INTEGRATED MODELS

- [X] Fee Transmittal Form Attached in Duplicate
- [X] Specification and Claim(s) [Total Pages 13]
- [X] Drawing(s) [Total Sheets 2]
  FORMAL
- Declaration [Total Pages 3]
  - [X] Newly Executed (Original or Copy)
  - [ ] Copy From Prior Application (37 CFR § 1.63(d))
    - [ ] Deletion of Inventor(s) (37 CFR § 1.63(d)(2)) (Signed Statement Attached)
- [X] Assignment Papers (Cover Sheet and Document(s))
- [ ] 37 CFR § 3.73(b) Statement (if applicable) [ ] Power of Attorney
- [ ] English Translation Document (if applicable)
- [X] Information Disclosure Statement (IDS)/PTO-1449
  - [X] Copies of IDS Citations
- [ ] Preliminary Amendment
- [X] Return Receipt Postcard (Specifically Itemized)
- [ ] Certified Copy of Priority Document(s)
- [ ] Other

--Continue Next Page--

If a Continuing Application

☐ Continuation ☐ Divisional ☐ Continuation-In-Part (CIP)

of prior Application No.: ;

Examiner : ; and

Group/Art Unit: .

☐ Cancel Claims:

For Continuations or Divisional Applications only: The entire disclosure of the prior application, from which an oath or declaration is supplied, as set forth above, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference.

Correspondence Address:

☒ Customer Number or Bar Code Label: 719

or

☐ Correspondence address below:

Name:

Address:

City: State: Zip Code:

Country:

****

Attorney/Agent: Steven D. Lundquist Registration No.: 42,816

Signature: Caterpillar Inc Date: 9/21/2000

PTO/SB/17 (12/99)
Approved for use through 09/30/2000. OMB 0651-0032
Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE

FEE TRANSMITTAL for FY 2000

Patent fees are subject to annual revision.
Small Entity payments must be supported by a small entity statement, otherwise large entity fees must be paid. See Forms PTO/SB/09-12.
See 37 C.F.R. §§ 1.27 and 1.28.

TOTAL AMOUNT OF PAYMENT ($) 690

Complete if Known	
Application Number	(Unassigned)
Filing Date	(Herewith)
First Named Inventor	XIAO CHEN ET AL.
Examiner Name	(Unassigned)
Group / Art Unit	(Unassigned)
Attorney Docket No.	99-463

METHOD OF PAYMENT (check one)

1. [X] The Commissioner is hereby authorized to charge indicated fees and credit any overpayments to:

Deposit Account Number: 03-1129

Deposit Account Name:

[X] Charge Any Additional Fee Required Under 37 CFR §§ 1.16 and 1.17

2. [ ] **Payment Enclosed:** [ ] Check [ ] Money Order [ ] Other

FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
101	690	201	345	Utility filing fee	690
106	310	206	155	Design filing fee	
107	480	207	240	Plant filing fee	
108	690	208	345	Reissue filing fee	
114	150	214	75	Provisional filing fee	

SUBTOTAL (1) ($) 690

2. EXTRA CLAIM FEES

	Extra Claims		Fee from below		Fee Paid
Total Claims	9 -20** =	0	x 18	=	0
Independent Claims	2 - 3** =	0	x 78	=	0
Multiple Dependent				=	

***or number previously paid, if greater; For Reissues, see below*

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
103	18	203	9	Claims in excess of 20
102	78	202	39	Independent claims in excess of 3
104	260	204	130	Multiple dependent claim, if not paid
109	78	209	39	** Reissue independent claims over original patent
110	18	210	9	** Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) ($) 0

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
105	130	205	65	Surcharge - late filing fee or oath	
127	50	227	25	Surcharge - late provisional filing fee or cover sheet.	
139	130	139	130	Non-English specification	
147	2,520	147	2,520	For filing a request for reexamination	
112	920*	112	920*	Requesting publication of SIR prior to Examiner action	
113	1,840*	113	1,840*	Requesting publication of SIR after Examiner action	
115	110	215	55	Extension for reply within first month	
116	380	216	190	Extension for reply within second month	
117	870	217	435	Extension for reply within third month	
118	1,360	218	680	Extension for reply within fourth month	
128	1,850	228	925	Extension for reply within fifth month	
119	300	219	150	Notice of Appeal	
120	300	220	150	Filing a brief in support of an appeal	
121	260	221	130	Request for oral hearing	
138	1,510	138	1,510	Petition to institute a public use proceeding	
140	110	240	55	Petition to revive - unavoidable	
141	1,210	241	605	Petition to revive - unintentional	
142	1,210	242	605	Utility issue fee (or reissue)	
143	430	243	215	Design issue fee	
144	580	244	290	Plant issue fee	
122	130	122	130	Petitions to the Commissioner	
123	50	123	50	Petitions related to provisional applications	
126	240	126	240	Submission of Information Disclosure Stmt	
581	40	581	40	Recording each patent assignment per property (times number of properties)	
146	690	246	345	Filing a submission after final rejection (37 CFR § 1.129(a))	
149	690	249	345	For each additional invention to be examined (37 CFR § 1.129(b))	
				Other fee (specify) _____	
				Other fee (specify) _____	

* Reduced by Basic Filing Fee Paid **SUBTOTAL (3)** ($) 0

SUBMITTED BY				Complete (if applicable)	
Name (Print/Type)	Steve D. Lundquist	Registration No. (Attorney/Agent)	42,816	Telephone	(314) 849-4079
Signature				Date	09/21/2000

WARNING:
Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

Description

METHOD AND APPARATUS FOR PROVIDING A SIMULATION OF A WELDING PROCESS USING INTEGRATED MODELS

This application claims the benefit of prior provisional patent application Serial No. 60/161,816 filed October 27, 1999.

Technical Field

This invention relates generally to a method and apparatus for modeling a welding process and, more particularly, to a method and apparatus for integrating models for a welding process to perform a thermal and structural analysis of the process.

Background Art

The process of welding materials has some amount of detrimental effect on the materials being welded. For example, materials being welded are subjected to residual stresses and distortions due to the extreme heat caused by the weld process.

In the past, attempts have been made to analyze and determine the effects of heat on materials from the welding process. One method in particular, the finite element method (FEM), uses finite element analysis to model the weld process, and has been widely used to analyze the thermal effects of welding. However, FEM can be extremely cumbersome to implement and very costly.

Another method used to determine the effects of heat on materials from the welding process incorporates an analytical solution to determine the thermal history of the welding process. For example, analytical solutions have been developed which use the superposition of point heat source solutions. These methods generally do not require the extremely cumbersome finite element analysis techniques previously used, and therefore provide a much more rapid analytical solution procedure. However, analytical methods do not account for such features as weld joint geometry. Furthermore, it may be desired to use both types of thermal models for some applications. For example, an analytical based model may be used for providing rapid, global solutions, and the FEM may be used to provide accurate temperature models for local areas of concern.

The present invention is directed to overcoming one or more of the problems as set forth above.

Disclosure of the Invention

In one aspect of the present invention a method for providing a simulation of a welding process using integrated models is disclosed. The method includes the steps of determining a model of a geometry of a set of materials to be welded, defining a set of coordinates of elements and nodes of the geometry model for a finite element analysis mesh, delivering the finite element analysis mesh

coordinates to a thermal analysis model, the thermal analysis model including an analytical solution model and a finite element analysis model, and determining a thermal analysis of the welding process, the thermal analysis responsively providing a thermal history of the welding process. The method further includes the steps of delivering the thermal history of the welding process to a structural analysis model, and providing a structural analysis of the welding process as a function of the thermal history.

Brief Description of the Drawings

Fig. 1 is a block diagram illustrating a preferred embodiment of the present invention; and

Fig. 2 is a flow diagram illustrating a preferred method of the present invention.

Best Mode for Carrying Out the Invention

Referring to Fig. 1, a block diagram illustrating a preferred embodiment of a set of integrated models 100 for performing a simulation analysis of a welding process is shown. The integrated models 100 work together to determine stresses and distortions of a material which is welded in the welding process. The stresses and distortions have an adverse effect on the strengths and characteristics of the material. Therefore, it is desired to model the stresses and distortions, and use the information from the models to determine methods which may minimize the adverse effects of welding.

In the preferred embodiment, an interconnection tool 114, such as a graphical user interface (GUI), interconnects the models into an integrated network of working models to determine stresses and distortions of the material. The interconnection tool 114 is preferably computer-based and may be configured to operate autonomously, through manual intervention, or some combination of the two modes. For example, the interconnection tool 114 may coordinate the modeling functions while displaying the status and results to a human, who may override the system or input additional information at any desired time.

A geometry modeler 102 determines the geometry model for the materials to be welded. Preferably, the geometry modeler 102 simplifies the geometry by removing unnecessary features of the materials from the model. Examples of such features include, but are not limited to, chamfers, holes, slight irregularities, and the like.

The geometry model data is then delivered to a meshing tool 104. The meshing tool 104 is used to generate a finite element analysis mesh, preferably by defining coordinates for elements and nodes which constitute the mesh. Finite element analysis techniques which use mesh coordinates are well known in the art and will not be described further.

A thermal analysis model 106 is used to perform a thermal analysis of the materials during the welding process. In the preferred embodiment, the

thermal analysis model 106 includes at least two models. An analytical solution model 108 provides a rapid analytical solution of the thermal process, i.e., welding process, for a global solution of distortions caused by the welding process. A finite element analysis model 110 provides local detailed analysis of residual stress from the welding process.

In the preferred embodiment, the analytical solution model 108 determines solutions of point heat sources, the point heat sources being obtained from heat input based on welding processes and reflected heat sources determined from adiabatic boundary conditions of the material. The total analytical solution is determined from superposition of all the point heat sources. The principle of obtaining reflected heat sources from adiabatic boundary conditions is well known in the art and will not be discussed further. The analytical solution model 108 provides a rapid solution for the complete welding process. However, the solution is not highly detailed. Therefore, the analytical solution model 108 is typically used when a fast, global solution is desired, and a high degree of detail is not needed.

The finite element analysis model 110 employs numerical computations of conditions at each of the desired node and element coordinates of the finite element analysis mesh. The finite element analysis model tends to be computationally lengthy and intensive. Therefore, the finite element analysis model 110 is generally used only when a detailed

analysis of a specific portion of the model is desired.

The information from the thermal analysis model 106 is compiled into a thermal history and delivered to a structural analysis model 112. In addition, the finite element mesh provided by the meshing tool 104 is delivered to the structural analysis model 112. The interconnection is automatically established in the interconnection tool 114. In the preferred embodiment, the thermal history is delivered from the thermal analysis model 106 to the structural analysis model 112 by way of an interface module 116. Preferably, the interface module 116 is automated from the interconnection tool 114 and is adapted to seamlessly connect the thermal solution from the analytical solution model 108, the finite element analysis model 110, or both, to the structural analysis model 112.

The structural analysis model 112 provides further analysis of the materials during the welding process. Typically, the behavior of the material during welding is analyzed and modeled. Examples of features analyzed include, but are not limited to, melting and remelting of the material, phase transformation of the material, cyclic effects of multiple weld passes, and the like. The stresses and distortions of the material are determined by the structural analysis model. Preferably, the determined stresses and distortions may be further analyzed and subsequently used to modify the welding process to

reduce the adverse effects of the extreme heat associated with welding.

Industrial Applicability

As an example of an application of the present invention, reference is made to Fig. 2, a flow diagram illustrating a preferred method of the present invention.

In a first control block 202, a model of the geometry of a set of materials to be welded is determined. In a second control block 204, a set of coordinates of elements and nodes of the geometry model is defined for a finite element analysis mesh. In a third control block 206, the finite element analysis mesh coordinates are delivered to a thermal analysis model 106. In the preferred embodiment, the thermal analysis model 106 includes an analytical solution model 108 and a finite element analysis model 110.

In a fourth control block 208, a thermal analysis of the welding process is determined as a function of at least one of the analytical solution model 108 and the finite element analysis model 110. The thermal analysis preferably provides a thermal history of the welding process. In a fifth control block 210, the thermal history of the welding process is delivered to a structural analysis model 112. In a sixth control block 212, a structural analysis of the welding process as a function of the thermal history

is provided. Preferably, the structural analysis includes information related to stresses and distortions caused by the welding process. This information may be used to develop methods and techniques to modify the welding process to minimize the stresses and distortions produced during subsequent welds.

Other aspects, objects, and features of the present invention can be obtained from a study of the drawings, the disclosure, and the appended claims.

Claims

1. A method for providing a simulation of a welding process using integrated models, the integrated models being interconnected by an interconnection tool to determine stresses and distortions of a material being welded, including the steps of:

determining a model of a geometry of the material;

defining a set of coordinates of elements and nodes of the geometry model for a finite element analysis mesh;

delivering the finite element analysis mesh coordinates to a thermal analysis model, the thermal analysis model including an analytical solution model and a finite element analysis model;

determining a thermal analysis of the welding process as a function of at least one of the analytical solution model and the finite element analysis model, the analytical solution model being adapted to provide a thermal history of the welding process for a global distortion analysis, and the finite element analysis model being adapted to provide a thermal history of the welding process for a detailed residual stress analysis;

delivering the thermal history of the welding process to a structural analysis model; and

providing a structural analysis of the welding process as a function of the thermal history.

2. A method, as set forth in claim 1, wherein providing a thermal history of the welding process for a detailed residual stress analysis includes the step of providing a thermal history of the welding process for a specific portion of the welding process.

3. A method, as set forth in claim 1, wherein providing a structural analysis of the welding process includes the step of modeling a set of characteristics of the materials being welded during the welding process.

4. A method, as set forth in claim 3, wherein characteristics of the materials include residual stresses and distortions.

5. A method, as set forth in claim 1, wherein determining a thermal analysis of the welding process as a function of the analytical solution model includes the steps of:

determining a set of adiabatic boundary conditions of the material being welded;

determining a set of reflected heat sources as a function of the adiabatic boundary conditions;

determining a set of point heat sources as a function of the reflected heat sources; and

determining a total analytical solution from superposition of the point heat sources.

6. A method, as set forth in claim 1, wherein determining a thermal analysis of the welding process as a function of the finite element analysis model includes the step of determining a set of numerical computations of conditions at each desired node and element coordinate of the finite element analysis mesh.

7. A method, as set forth in claim 1, wherein delivering the thermal history of the welding process to a structural analysis model includes the step of delivering the thermal history by way of an interface module.

8. An apparatus for providing a simulation of a welding process using integrated models, the integrated models being interconnected by an interconnection tool to determine stresses and distortions of a material being welded, comprising:

a geometry modeler adapted to determine a model of a geometry of the material;

a meshing tool adapted to define a set of coordinates of elements and nodes of the geometry model for a finite element analysis mesh;

a thermal analysis model adapted to receive the finite element analysis mesh, determine a thermal analysis of the welding process, and responsively provide a thermal history of the welding process, wherein the thermal analysis model includes:

an analytical solution model adapted to provide a thermal history of the welding process for a global distortion analysis; and

a finite element analysis model adapted to provide a thermal history of the welding process for a detailed residual stress analysis; and

a structural analysis model adapted to provide a structural analysis of the welding process as a function of the thermal history.

9. An apparatus, as set forth in claim 8, wherein the interconnection tool is a graphical user interface.

Abstract of the Disclosure

METHOD AND APPARATUS FOR PROVIDING A SIMULATION OF A WELDING PROCESS USING INTEGRATED MODELS

A method and apparatus for providing a simulation of a welding process using integrated models which are interconnected by an interconnection tool to determine stresses and distortions of a material being welded. The method and apparatus includes determining a model of a geometry of a set of materials to be welded, defining a set of coordinates of elements and nodes of the geometry model for a finite element analysis mesh, delivering the finite element analysis mesh coordinates to a thermal analysis model, the thermal analysis model including an analytical solution model and a finite element analysis model, and determining a thermal analysis of the welding process, the thermal analysis responsively providing a thermal history of the welding process. The method and apparatus further includes delivering the thermal history of the welding process to a structural analysis model, and providing a structural analysis of the welding process as a function of the thermal history.

Fig. 1.

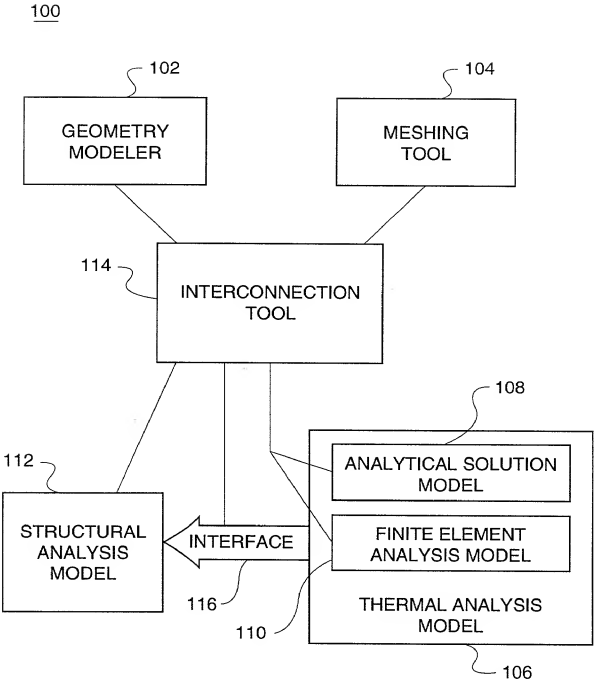
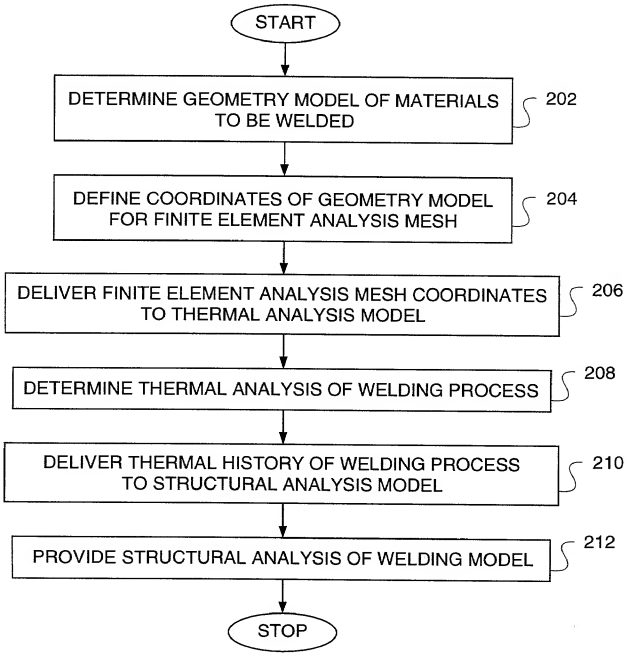


Fig. 2.


START
DETERMINE GEOMETRY MODEL OF MATERIALS TO BE WELDED
202
DEFINE COORDINATES OF GEOMETRY MODEL FOR FINITE ELEMENT ANALYSIS MESH
204
DELIVER FINITE ELEMENT ANALYSIS MESH COORDINATES TO THERMAL ANALYSIS MODEL
206
DETERMINE THERMAL ANALYSIS OF WELDING PROCESS
208
DELIVER THERMAL HISTORY OF WELDING PROCESS TO STRUCTURAL ANALYSIS MODEL
210
PROVIDE STRUCTURAL ANALYSIS OF WELDING MODEL
212
STOP

DECLARATION AND POWER OF ATTORNEY

I, XIAO CHEN, declare that I am a citizen China, residing at Peoria, Illinois, and that I believe I am one of the original, first, and joint inventors together with YI DONG AND ASHOK NANJUNDAN of the subject matter which is claimed and for which a patent is sought on the invention entitled:

METHOD AND APPARATUS FOR PROVIDING A SIMULATION OF A WELDING PROCESS USING INTEGRATED MODELS

the specification of which is attached hereto.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims.

I hereby claim the benefit under Title 35, United States Code, §119(e) of any United States provisional application(s) listed below:

Provisional Application Serial Number: 60/161,816
Provisional Application Filing Date: October 27, 1999

I acknowledge the duty to disclose to the Patent and Trademark Office all information known to be material to patentability as defined in §1.56. I further declare that no application for patent or inventor's certificate on this invention has been filed in any country foreign to the United States of America prior to this application by me or my legal representatives or assigns.

I hereby appoint Steve D. Lundquist, Patent Office Reg. No. 42,816, telephone (314) 849-4079, Joseph W. Keen, Patent Office Reg. No. 28,432, telephone (309) 675-5753, Robert J. Hampsch, Patent Office Reg. No. 36,155, telephone (309) 675-5214, and R. Carl Wilbur, Patent Office Reg. No. 36,056, telephone (309) 675-5847, my attorneys and/or agents, with full power of substitution and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected with this application. Please address all correspondence to: Steve D. Lundquist, Caterpillar Inc., Intellectual Property Department, AB6490, 100 N.E. Adams Street, Peoria, Illinois 61629-6490.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements are made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

09/12/00

XIAO CHEN — Date

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DECLARATION AND POWER OF ATTORNEY

I, YI DONG, declare that I am a citizen China, residing at Peoria, Illinois, and that I believe I am one of the original, first, and joint inventors together with XIAO CHEN AND ASHOK NANJUNDAN of the subject matter which is claimed and for which a patent is sought on the invention entitled:

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Yi Dong 09/12/00

YI DONG Date

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DECLARATION AND POWER OF ATTORNEY

I, ASHOK NANJUNDAN, declare that I am a citizen India, residing at Savoy, Illinois, and that I believe I am one of the original, first, and joint inventors together with XIAO CHEN AND YI DONG of the subject matter which is claimed and for which a patent is sought on the invention entitled:

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N Ashok. 09/12/2000

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